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JOINT INSTITUTE FOR ADVANCEMENT OF FLIGHT SCIENCES

FINAL REPORT

NAG1-852 - NONLINEAR ANALYSIS AND MODELING OF TIRES

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FOREWORD

This is a brief final technical report prepared under NASA Grant No. NAG1-852. It summarizes the work done by the Technical Director, Professor Ahmed K. Noor and the GWU staff. A detailed description of the work is given in the enclosed publications.

ABSTRACT

The overall objective of the study is to develop efficient modeling techniques and computational strategies for: a) predicting the nonlinear response of tires subjected to inflation pressure, mechanical and thermal loads; and b) determining the footprint region, and analyzing the tire-pavement contact problem, including the effect of friction. Two computational strategies have been investigated. In the first strategy the tire is modeled by using two-dimensional shear flexible mixed shell finite elements and the contact conditions are incorporated into the formulation by using a perturbed Lagrangian approach.

The second strategy exploits the axial symmetry of the undeformed tire, and has the following three key elements: a) representation of the shell variables and loads by a Fourier series in the circumferential coordinate combined with the use of finite elements in the meridional direction; b) application of operator splitting/reduction technique to uncouple the different Fourier harmonics; and c) addition of two-dimensional finite elements in the contact region to improve the approximation in that region. The compatibility between the different models in the contact zone is maintained by using the methodology of global local analysis.

The two specific tasks completed under the present grant are: a) development of a sophisticated computational model for the Space Shuttle orbiter nose-gear tire; and b) development of a computational procedure for the solution of frictionless contact problems of aircraft tires.

The NASA Technical Officer is Mrs. Martha Robinson, Impact Dynamics Branch, Structural Dynamics Division, NASA Langley Research Center.

SUMMARY OF RESEARCH WORK

A brief description of the work done during the period February 1, 1988 to April 30, 1990 in each of the two tasks completed under this grant, is given subsequently. The detailed description of the research results is given in the enclosed publications.

Computational Model for the Space Shuttle Orbiter Nose-Gear Tire

The computational model of the tire is based on a two-dimensional laminated anisotropic shell theory with the effects of variation in material and geometric parameters, transverse shear deformation and geometric nonlinearities included. Measurements were made to determine the shape of the tire cross section, and the thickness variation. The tire section was divided into segments with different number of layers, different material properties (corresponding to different cord content in the composite), and different fiber orientation. Spline interpolation was used to smooth out the measured data, and to obtain the geometric and material characteristics of the two-dimensional shell model (see Refs. 1 and 3 in the list of publications).

Computational Procedure for the Solution of Frictionless Contact Problems of Aircraft Tires

In the computational procedure for tire contact the contact conditions are incorporated into the formulation by using a perturbed Lagrangian approach with the fundamental unknowns consisting of the stress resultants, the generalized displacements, and the Lagrange multipliers associated with the contact conditions. The finite element arrays are obtained by using a modified two-field mixed variational principle. The modification consists of augmenting the functional of that principle by two terms: the Lagrange multiplier vector associated with the nodal contact pressures and a regularization term which is quadratic in the Lagrange multiplier vector.

The shape functions used in approximating the generalized displacements and the Lagrange multipliers are selected to be the same and are different from those used in approximating the stress resultants. The stress resultants and the Lagrange multipliers are allowed to be discontinuous at interelement boundaries. The nonlinearities due to both the large displacements, moderate rotations, and the contact conditions are combined into the same iteration loop and are handled by using the Newton-Raphson iterative scheme.

Numerical results were conducted for the Space Shuttle orbiter nose-gear tire when subjected to inflation pressure and pressed against a rigid pavement. Comparison is made with the experiments conducted at NASA Langley. The detailed information presented herein is considerably more extensive than previously reported and helps in gaining physical insight about the response of the tire. The numerical studies have demonstrated the high accuracy of the mixed models and the effectiveness of the computational procedure, which combines both the geometrically nonlinear terms and the contact conditions in one iteration loop. Also, the potential of the foregoing computational procedure and means of enhancing its efficiency are discussed. Results of this study are included in two NASA TP's, one of which has also been published as a journal article. The other one will also be published in archical journals.

LIST OF PRESENTATIONS AND PUBLICATIONS COMPLETED UNDER THE GRANT

1. Noor, A. K., Kim, K. O. and Tanner, J. A., "Nonlinear Analysis of Aircraft Tires Via Semianalytic Finite Elements," in Computational Mechanics of Nonlinear Behavior of Shell Structures, edited by W. B. Kratzig and E. Onate, Springer-Verlag, Berlin, 1989; also in Finite Elements in Analysis and Design, Vol. 6, 1990, pp. 217-233; also published as NASA TP-2977, April 1990.
2. Noor, A. K. and Kim, K. O., "Mixed Finite Element Formulation for Frictionless Contact Problems," NASA TP-2897, April 1989; also in Finite Elements in Analysis and Design, Vol. 4, 1989, pp. 315-332.
3. Kim, K. O., Tanner, J. A. and Noor, A. K., "Computational Methods for Frictionless Contact with Application to Space Shuttle Orbiter Nose-Gear Tires," NASA TP (to appear).